Issued December 9, 1919.

Hawaii Agricultural Experiment Station
HONOLULU

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PRESS BULLETIN No. 54.

Preliminary Report on Root Rot In Hawaii

(LAHAINA CANE DETERIORATION, PINEAPPLE WILT, TARO ROT, RICE ROOT ROT, BANANA ROOT ROT.)

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The term root rot is a collective term commonly applied loosely to root diseases of plants in general, but it is used in this preliminary report in a restricted sense to denote the most significant symptom found in such diseases as Lahaina cane deterioration so-called, pineapple wilt, etc. Such root rots or root failures are among the most important diseases of economic plants in Hawaii.

In this Territory, as in practically all sugar cane growing countries, a disease of the Lahaina cane (apparently the same as the Bourbon variety) of obscure origin has caused grave concern for many years. Many theories as to the cause of the so-called deterioration of this popular variety have been vigorously investigated without striking result in demonstrating the cause of the disease or in restoring this variety to culture in localities in which it has failed. In Hawaii the situation has been met in a very creditable manner by the Experiment Station of the Hawaiian Sugar Planters' Association through the development, selection, and propagation of resistant varieties, while in other countries other varieties have to a greater or less extent replaced the Bourbon type. Nevertheless, various theories as to the cause of failure have continued to be presented and investigated, an indirect tribute to the merit of the Lahaina variety. Of the latter there is no question, nor of the benefit to these Islands, could this variety be generally restored to profitable culture. Evidently the interest in the possible cause of failure of the Lahaina cane will not subside until a satisfactory explanation is found. The occurrence of the disease in plant cane on virgin soil, with the attack of another variety, H 146, and other manifestations of

the increased virulence of the disease during the past year, have added to the seriousness of the situation.

Pineapples, second agriculturally only to cane in importance in these Islands, are attacked to an increasing extent by a root rot trouble popularly called "wilt." A similar disease is prevalent in other pineapple-growing countries. In the Hawaiian Islands, this disease has recently caused heavy losses with first plantings on virgin soil. With but the one preferred variety (Smooth Cayenne) of satisfactory quality, the situation as regards the future of this crop is admittedly grave. Evidently the past year has offered conditions unusually favorable to the development and spread of the pineapple "wilt" and the Lahaina cane disease.

In Hawaii the importance of root rots of other crops is perhaps less appreciated only because the crops affected are less extensively cultivated. The following diseases, in which root failure is a striking symptom or sign of disease, are considered as essentially in the same category as the Lahaina disease and pineapple "wilt" under discussion and are being studied simultaneously therewith, although the writer's investigation of these troubles was begun much earlier: Taro rot, banana root rot, (leaf chlorosis and center leaf necrosis), and a rarely observed, and little sought, it must be admitted, root rot of rice.

Preliminary investigations of root rot diseases of banana and taro were begun in October, 1916, and continued intermittently thereafter at favorable opportunities, with emphasis placed on this line of investigation the latter part of 1918. In January, 1919, typically diseased Lahaina cane and pineapple plants suffering from "wilt" were brought to the writer's attention. The first observations with the microscope were of such a convincing nature that the two diseases were immediately diagnosed as parasitic in character, of fungus origin, and apparently identical. The essential identity of the two diseases and their cause was announced in the local press on February 5, 1919.[1]

Considerable material included in the writer's unpublished reports is considered nonpertinent in the light of subsequent observations, but several sentences which are significant may well be quoted for the sake of record. Speaking of cane and pineapple root rot (February 4, 1919):

> "The undersigned wishes to go definitely on record as having observed in connection with and apparently causing the disease of the roots, a fungus. Apparently the mode of attack is somewhat as follows, basing the judgment on observations in the field, the statement of the planters, and the reaction of plants placed in water and left a few days, changing the water daily: The roots grow well until the

[1] Pacific Commercial Advertiser, Honolulu, T. H.

fungus is encountered, and if the conditions of the soil are suitable, the root is attacked at the tip, in the vicinity of the root hairs, or a canker may form in advance of the point where the root hairs are found, etc. * * We may say, then, that the action of the fungus appears to be a *damping-off* of the roots somewhat in the same way as some *Rhizoctonias* damp-off the stems of seedlings. Sufficient data are not at hand to justify further views as to the method or mode of attack, the writer wishing chiefly to establish the priority of the view that a fungus is responsible for the diseased condition obtaining.

"A fungus mycelium and hypha are found growing within the root hair cells of living young roots. Cankers apparently brought about by the same type of fungus are present on young roots, and when at the point of origin of the young roots or rootlets, girdle the same in some cases. This condition of root hair inhabitation and girdling exists in roots of both Lahaina cane and H 146 variety when suffering from root disease at Waipahu and in pineapple ("wilt") roots from Waipio and the foot of the Nuuanu Pali."

In this preliminary report it is not intended to furnish detailed information on the various root rot troubles under survey, but merely to outline the problem and supply a brief sketch of the working theory and results, and to record the essential identity of the diseases mentioned, together with the proof as to the cause of Lahaina disease so far as completed.

It is appreciated that more exhaustive studies may show several organisms capable of inducing root rot of our chief crops. If such is the case, the lack of characterization of the separate diseases necessarily makes difficult the determination of the individual causes. The writer's preliminary observations, in contrast to those of other investigators, having been such as to lead him to conceive of Lahaina deterioration and pineapple "wilt" as parasitic diseases of fungus origin, the parasite being active under certain soil conditions, and the two diseases being apparently identical in nature with several other root rots, the investigation of all was carried along at the same time in a systematic manner. Numerous organisms were isolated from the diseased roots in an attempt to obtain in pure culture a parasitic fungus corresponding to the one constantly seen in the sound tissues of the roots adjacent to those tissues showing the early stage of root disease (Pls. 4 and 5). After numerous disappointments, such a fungus was readily obtained, once the necessary technique was developed. This fungus from root rot of cane was found to closely resemble a fungus in cultivation for some years from taro rot and rice root rot. The similar mycelium and spores being present in the several root rots, rice, taro, cane, pineapple,

and banana, and a parasitic type of fungus allied to *Pythium* having been isolated from the first three, it was believed that one definite cause of some of our root rot trouble had been found. The nature of this parasitic fungus now under investigation is such as to suggest lines of experimental work in laboratory and field, for determining possible control methods. Likewise, if this fungus is accepted as the cause of Lahaina disease and pineapple "wilt," the contradictory features of the two diseases are understandable (e. g. Pl. 2B).

It may be noted that a fungus theory as to the causes of the deterioration of Lahaina cane and pineapple "wilt" disease has been advanced many times by various investigators in several countries. As far as the literature examined indicates, no one seems to have linked the two diseases together, and in general results seem to have been negative or inconclusive, no proof being offered, so far as the writer is aware, that these diseases are caused by a fungus or other parasite. One of the fungi said[1] to be the cause of pineapple "wilt" is reported as a root hair inhabiting fungus. No proof of causal relation to the disease is offered.

It should be mentioned here that soon after announcement was made in the local press that apparently the cause of Lahaina disease and pineapple "wilt" had been found by the present writer, and the identity of these two diseases stated, H. L. Lyon,[2] of the Hawaiian Sugar Planters' Experiment Station reported the finding of resting spores of a protozoa-like organism, which he said probably belonged to the *Chytridineae,* in the affected roots of Lahaina cane and pineapples. He suggested the possible relation of these bodies to the disease and the possible identity of the diseases as to cause. He has subesquently noted[3] that if root diseased cane and pineapple plants are placed in water culture, without removing the rotted roots, new roots develop and after a time collapse, the same protozoan type spore bodies being present therein as in the original diseased roots. It was specifically stated that no mycelial fungus was associated with these bodies. These spore bodies mentioned by Lyon are considered by the present writer to be identical with those discussed in the following pages and are believed to be a definite stage in the development of the *Pythium*-like fungus. While some of the rounded spore bodies appear to be conidia (sporangia) and resting conidia, the majority are thought to be oospores within the remnants of the oogonium. The thick-walled spores generally are not found in

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[1] Stockdale, F. A., Fungous disease of pineapples. West Indian Bulletin VIII, 1907, p. 159.

[2] Lyon, H. L., Root rot or "Lahaina disease." H. S. P. A. Expt. Sta., Progress of Work, January, 1919, p. 4. (Dated February 9, 1919.)

[3] Lyon, H. L., A preliminary report on the root rot organism. Hawaiian Planters' Record, vol. XXI, No. 1, July, 1919, pp. 2-8.

the young lesions but abundantly in the softened tissues, and the mycelium which has preceded the oospores is generally not visible, though if searched for traces of it are occasionally seen attached to the vestiges of the oogonium-like wall surrounding the oospore (Pl. 7B).

Studies conducted by the writer during the past seven months are a working out of the fungus theory conceived in January, 1919, and they serve not only to confirm the theory (Pls. 1, 2A, 3) but they offer strong proof that a fungus allied to *Pythium*, isolated from affected cane roots, is capable of causing a root failure in Lahaina cane. Without going into details, it may be said that one of the large number of fungi isolated from Lahaina cane, when grown in pure culture and placed in the steam-sterilized soil in which Lahaina cane was being grown in pots, produced root decay and strikingly checked the growth of the cane in a few weeks (Pls. 2A and 3). The seed in this test was top seed (cuttings) disinfected in 1:1,000 bichlorid of mercury for five minutes, planted in steam-sterilized soil, and watered only with distilled water. The latter item necessitated the conduction of the experiment on only a limited scale. The uninoculated control plants (Pl. 2A), as well as plants in soils inoculated with two other suspected fungi, developed vigorously the while and were soon about two feet higher than those in soil inoculated with the *Pythium*-like fungus, and the shoots were much larger and stronger in appearance. The root systems (Pl. 3) of the controls remained healthy, while those of the plants in inoculated soil were badly diseased. In the latter there was a striking lack of development of the hair-like feeding roots.

The fungus used for inoculation was recovered in pure culture from the diseased roots. This, in addition to the constant occurrence of an organism in association with a disease, is generally considered proof of causal relationship to the disease. Sufficient time has hardly elapsed to determine whether the fungus is constantly present in Lahaina disease, and it must be admitted that the number of plants inoculated in the test was small. The test must be repeated, and cross inoculations should be made with the same type fungus from the other host plants. Tests now under way show that the fungus forms some root lesions on H 109 and Yellow Caledonia varieties, both of which are resistant to the disease in the field. In other words, it appears that the resistance of these two varieties is relative, not absolute. *Pythium* sp. is not unknown as a root rot parasite of field crops, as it causes a serious root rot of sugar beets and other crops.

The observations of the writer in the field and the laboratory convince him that the same or a similar fungus is responsible for a most destructive type of pineapple "wilt" (root rot), and a root rot of taro, rice, and Chinese bananas (*Musa cavendishii*). The diseases are a damping-off of the roots and consequent

checked development of the hair-like feeding roots, as conceived for Lahaina disease and pineapple "wilt", and are apparently caused by the so-called damping-off fungus of seedlings, *Pythium debaryanum,* or a related form. The mode of attack is as quoted above from the prognosis. The mycelium of the *Pythium*-like fungus is nonseptate when young, later becoming septate, and, in the roots of cane and banana at least, is often stained reddish-brown by the coloring matter liberated by the roots in response to the injury. The mycelium occurs in both the septate and the nonseptate form in the cells of the host tissue, and when in the epidermal cells of the roots, branches frequently run out into the root hairs. The most common points of attack are wherever tender young root tissue occurs, root tips, etc., or at any point on the young roots.

A positive identification of the fungus as to species is not necessary nor warranted at this time by the morphological studies, it being sufficient to state that in cultures as well as in the host tissue it resembles *Pythium debaryanum* (Pls. 5, 6, 7, 8.) The cane fungus with which a positive inoculation has been secured, with subsequent re-isolation of the fungus, is apparently identical with the taro root rot organism obtained in pure culture by the writer in May, 1918. In the roots after attack, as well as in culture, the fungus forms numerous conidia (sporangia) and resting spores (conidia and apparently oospores). These bodies are present at least in the affected tissues in the roots of cane, taro, pineapple, and banana, and in cultures from rice, taro, and cane. In pure cultures of the organism from rice, taro, and cane, undoubted oospores have been observed. Conidia and resting spores (oospores apparently) are also present in the affected and softened roots of Lahaina cane in soil inoculated with the pure culture of mycelium of the *Pythium*-like fungus. Swollen, globular mycelium, typically present in the diseased tissues, is thought to belong to this fungus (Pls. 4, 5, and 6).

Since the incubation period, i. e., in this case the time elapsing from inoculation of the soil to the advent of symptoms of disease (checked growth), was about two weeks, it is evident that the fungus requires only a short period of favoring conditions to initiate attack. In cane, possibly only in certain physical soil types, the time the soil is wet during periodic irrigations is probably sufficient for the infection of new roots which may have formed in response to the same and previous irrigations. In pineapples in the wilt-affected localities, there is probably sufficient precipitation to allow the attack to occur occasionally at least, or moisture conditions favorable to root development and extension are favorable to the fungus, and the attack may coincide with root extension. The symptoms, checked growth, etc., are subsequently manifested and become aggravated by periods of drought, when the plants lose more water by transpiration than

the meager roots can supply. It is not extraordinary, if *Pythium* is the active agent in causing the disease, that such reported facts as simple removal of a wilt plant and replanting the same or another may give rise to a healthy growing plant.

In seeking to control a disease, logically the first step is to determine the cause, and then the conditions under which this cause is active. The writer's future studies for some time are designed to throw such additional light as may be possible on these preliminary phases of the problem, for without appreciation of these matters the finding of possible control methods is indeed remote. With further knowledge it will likely become evident whether or not practical control measures are within the range of probability. With taro rot it is of some significance that drying, resting, and aerating the sick soils, as well as the application of lime to the soil and the addition of copper sulphate to the irrigation water, respectively, have been markedly beneficial to the crop.

The fungus *Pythium,* which the root rot fungi under study closely resemble, is generally considered as favored by a stagnant condition of the soil, high soil temperature, and high moisture content. As already suggested in the writer's earlier unpublished reports, studies of the physical characteristics of our affected soils will likely prove of value in determining cultural modifications looking to control. In Java,[1] investigators reached the conclusion that a similar root rot there was not due to organisms found colonizing on the roots, among which *Pythium* is named, but to compacting the soil, etc. Since the Lahaina cane inoculation test above mentioned was conducted in good potting soil, and the control plants grew well, though treated in the same manner except that none of the *Pythium*-like fungus was introduced, the least that we can say is that our preliminary results support a conclusion at variance with the findings in Java. Whether the Java disease and the similar deterioration of the Lahaina type of cane in several other countries is the same as the disease occurring in the Hawaiian Islands is not known, though there is much in the literature indicating such identity.

In the Islands, especially as regards pineapple culture, field practice, groping in obscurity as to the cause of "wilt," has already made progress along the line that would be advised, should our further work confirm the preliminary conclusion that a species of *Pythium* or related fungus is the active cause of the wilt and root rot. Field practices most in favor for sometime have placed emphasis on drainage, aeration, etc., with hilling up as a means to this end. Flocculation of the soil particles of some soils at least is desirable, and in this connection it might be noted

[1] Kamerling, Z., Verslag van het Wortelrot, Oenderzoek, Soerabaia, 1903; abstracted by Sorauer, P., Manual of Plant Diseases, vol. I, pp. 227, 228.

that common salt has been reported as of advantage in controlling damping-off diseases in greenhouses. In general, where the disease is present, an optimum supply of capillary water, with adequate soil aeration, is the indicated soil condition most likely to encourage healthy root development.

SUMMARY.

1. Observations, field and laboratory studies confirm the theory advanced in February, 1919, as to at least one active cause of Lahaina disease (root rot) of cane. This cause is a parasitic fungus with a definite mycelium and of the *Pythium debaryanum* type. Apparently the same fungus or a closely related species is responsible for pineapple "wilt" (root rot), taro rot, banana center leaf necrosis (root rot), and a root rot of rice.

2. The parasitic fungus is the one observed and recorded in February, 1919, in cane and pineapple roots, attacked by Lahaina disease and "wilt," respectively, and is now, as then, found associated with lesions on the roots, near the tips, at the tips, and on other tender parts of the young roots indiscriminately, as well as existing as wandering hyphae, nonseptate to septate depending on conditions, in surface cells, root hair cells, and cells of the cortex of roots in the earliest stages of attack.

3. This type of fungus was first secured in pure culture from rice root rot in September, 1917, and from taro rot in May, 1918, and subsequent study in 1918 showed that the latter was capable of producing a rot of the taro corms. In taro rot in the field, the rot of the edible corm is preceded by a rot of the young roots as in cane and pineapples. The cane organism, isolated in pure culture and inoculated into steam-sterilized soil in which Lahaina cane from top seed disinfected in bichlorid of mercury solution 1:1,000 for five minutes was growing, attacked the roots. The plants were watered only with distilled water. Noticeable symptoms of disease appeared on the plants in about two weeks. The fungus was re-isolated in pure culture from this material.

4. This root rot fungus found parasitic on Lahaina cane is tentatively considered to belong to the *Pythiae* of the *Saprolegniaceae* and probably identical with *Pythium debaryanum*.

5. The nature of the fungus is such that, should further work substantiate the preliminary results, in our research we should tentatively put emphasis on physical studies of our soils in seeking control measures, and in the field studies give added attention to drainage and aeration, and possibly modify the physical properties through the application of chemicals which will flocculate our colloidal soils, if such chemicals can be found. With irrigated crops the addition of copper sulphate to the water may prove of value, as experiments have indicated with taro.

PLATES

PLATE 1. Comparative root systems of three-month-old Lahaina cane in sick Waipio soil (2); in same soil disinfected with formaldehyde (36); and in same soil steam-sterilized (12).

2. A, Lahaina cane, 60 days old, in steam-sterilized soil. Left, uninoculated control; right, in soil inoculated with the *Pythium*-like fungus five weeks before being photographed. (See Plate 3 for root systems.)

   B, A phenomenon of Lahaina cane disease in the field at Waipio; two sticks from the same stool, one of which succumbed and the other recovered. (Note the shortened internodes produced during period of diseased condition.)

3. Root systems of plants in Plate 2A. Control at left, plant in soil inoculated with *Pythium* at right.

4. Types of root hair and epidermal cell inhabitation by fungus mycelium in Lahaina cane root disease. A swollen, globular mycelium, as well as a cylindrical type, appears to belong to the *Pythium*-like fungus in a natural habitat. X 1000.

5. A, Portion of feeding mycelium in young root from base of sprout growing from seed piece (Lahaina cane). Apparent penetration of cell walls by amœboid processes. X 1000.

   B, Swollen, hyaline, finely granular feeding mycelium suggesting plasmodium. Root from joint of seed piece (Lahaina cane). X 1000.

   C, Tangential surface section of dark colored lesions on young root of Chinese banana (*Musa cavendishii*). Dark mycelium apparently stained brown by pigment from the discolored cell walls, etc. Note resemblance of mycelium to D from Lahaina cane. X 1000.

   D, Section of Lahaina cane root growing in steam-sterilized soil inoculated with the *Pythium*-like fungus. Some of the mycelium present has *Pythium*-like swollen ends and closely resembles that shown in C. X 1000.

6. Swollen globular mycelium apparently belonging to the *Pythium*-like fungus in a natural habitat. Note the wandering, attenuated portion penetrating the cell walls. This type of plasmodium-like mycelium is frequently found in Lahaina root disease, in the field material, as well as in affected roots in sterilized inoculated soil. This stage is thought to immediately precede resting spore formation. (Variety H 109 in inoculated soil.) X 1000.

7. A, Resting spore of *Pythium*-like fungus in cell of Lahaina cane root. Large numbers are typically present in the root disease after the tissues have partially broken down. They vary considerably in size and often are held to an oblong shape by the cell walls. Apparently these are oospores within vestiges of the oogonium wall. X 1000.

   B, Spores, similar to those in A, in cells of banana root. Barely visible traces of mycelium and possible antheridium still attached to the oogonium-like outer wall are indicated in the lower spore. X 1000.

8. A-D, *Pythium* from rice in culture (X 1000); A, Conidium (sporangium) or young oogonium forming; B, Egg cell (oosphere) developing in oogonium; C, Egg cell (a) being fertilized by antheridium (b); D, Thick-walled mature oospore (egg spore) freed from oogonium.

   E, *Pythium* in culture from Lahaina cane forming same sort of oospore (X 1000); (a) egg cell or oosphere in oogonium, (b) oogonium, (c) antheridium(?).

   F, From the same culture as E. Fertilization effected, oospore with very thick brown wall.

   G, Root hair cell of Lahaina cane containing several spores. These are apparently hyaline oospores freed from the oogonia walls, or possibly resting sporangia (conidia). X 1000.

Note: Plates 4-8 from camera lucida drawings.


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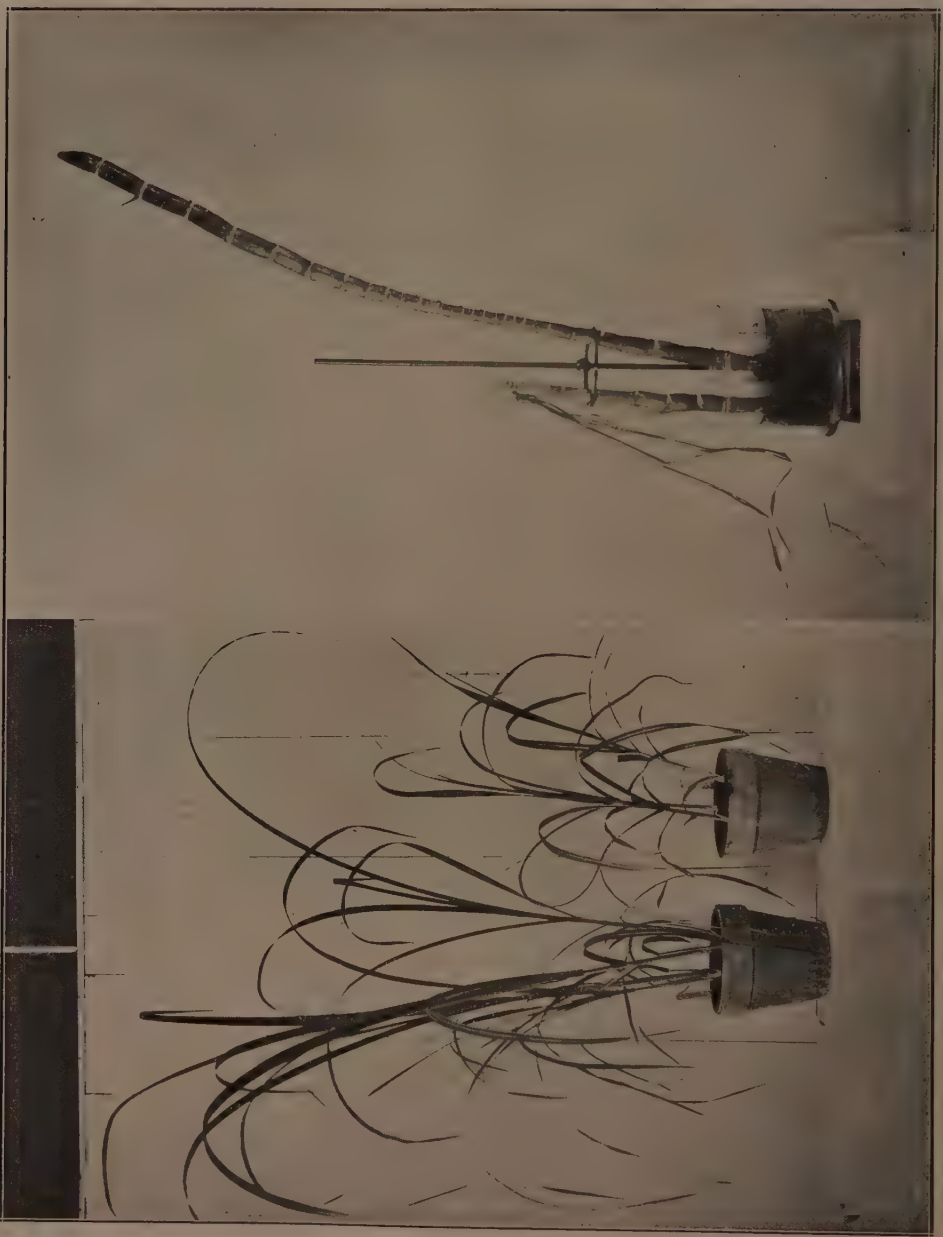

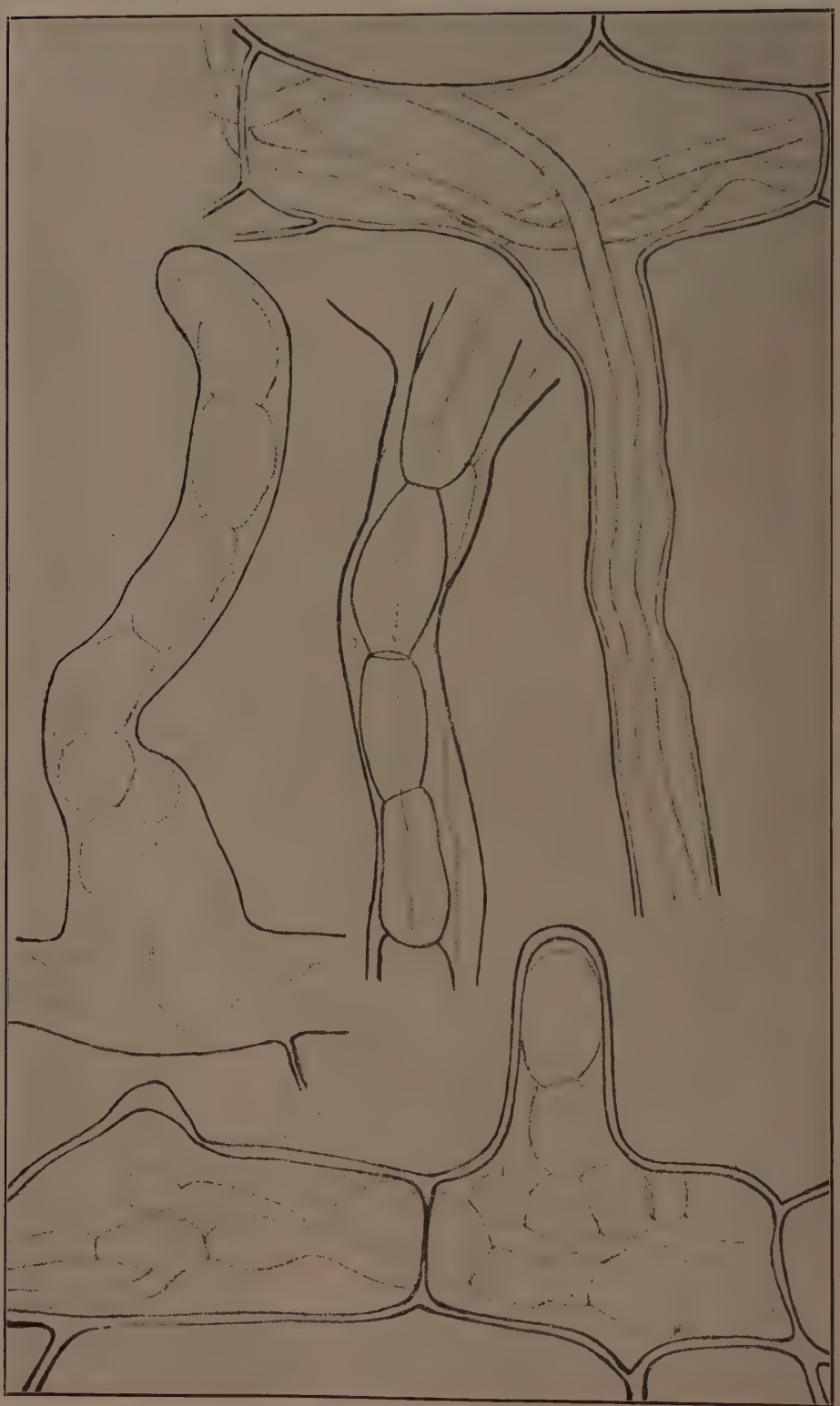

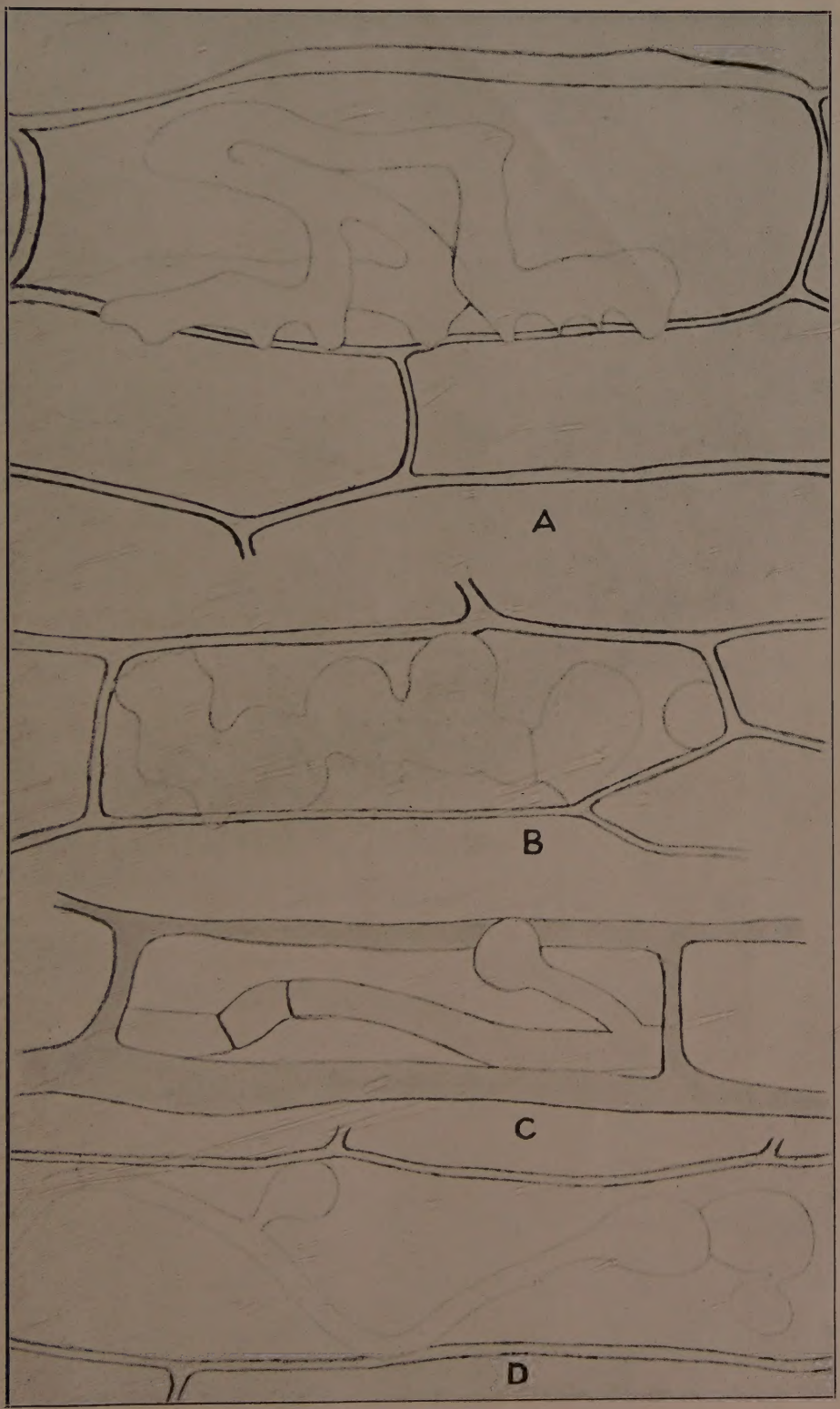
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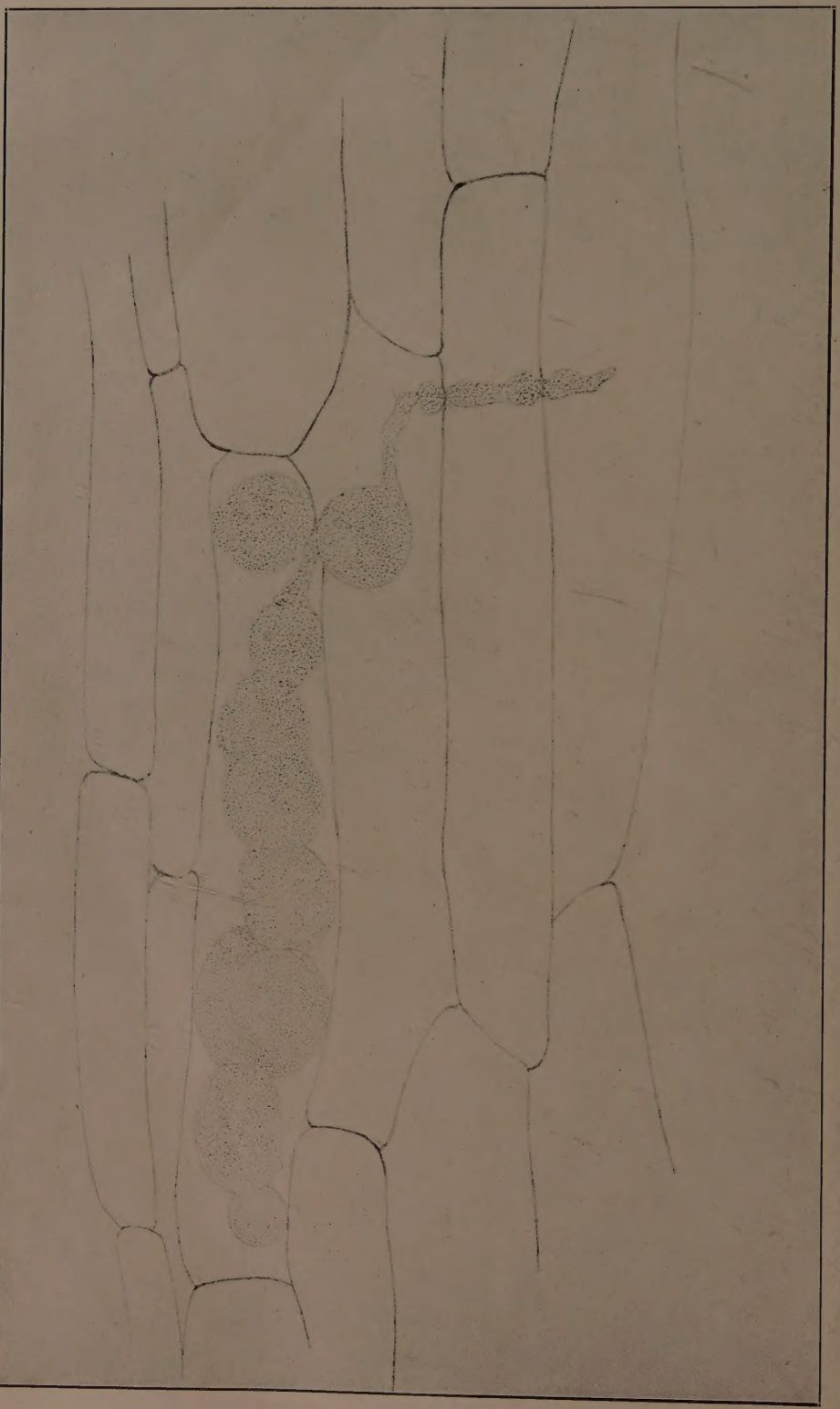

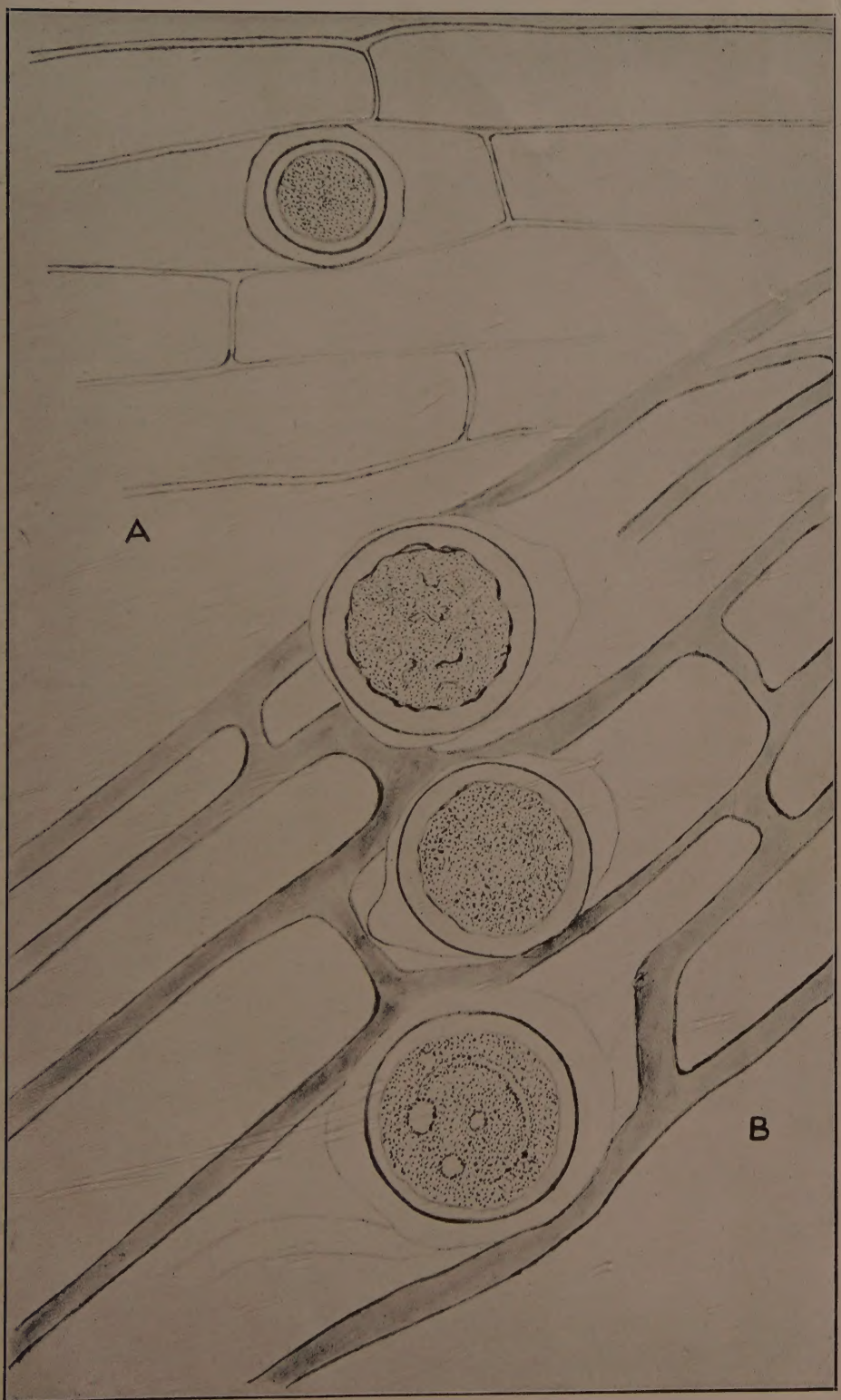
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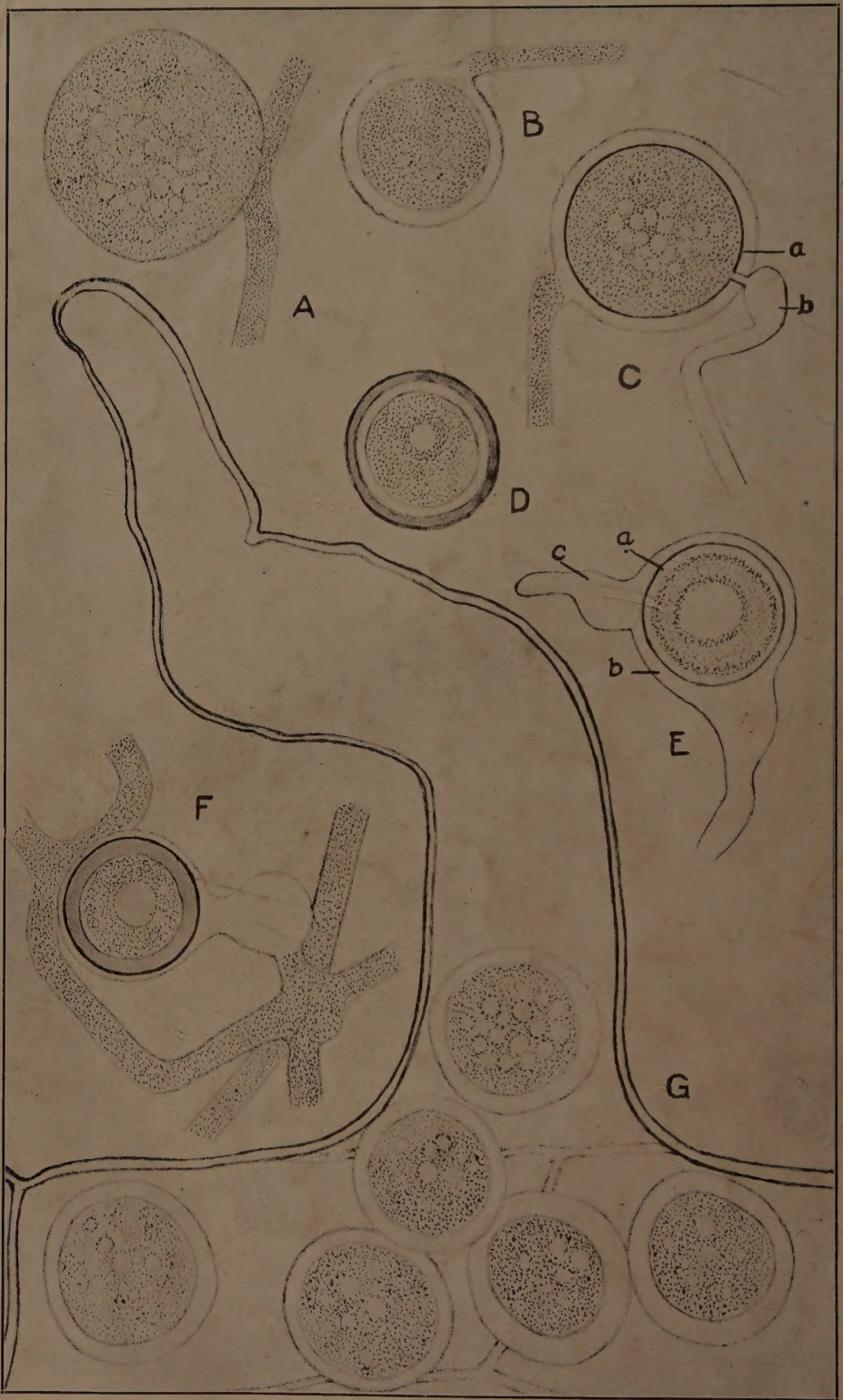
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